RESEARCH TRIANGLE INSTITUTE
Air Pollution Control Technology Verification Center

TO: Mobile Sources ETV Technical Panel Members
FROM: Douglas VanOsdell, Mobile Source Verification Task Leader
DATE: August 6, 2001
SUBJECT: Technical Panel Draft No. 5 of *Generic Verification Protocol for Retrofit Catalyst, Particulate Filter, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*

Technical Panel Draft No. 5 of the *Generic Verification Protocol for Retrofit Catalyst, Particulate Filter, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines* is attached for your review prior to the August 14, 2001, Technical Panel (TP) and vendor meeting. This "fifth draft" includes input from the two May teleconferences, the EMA, MECA, OTAQ Washington, as well as editorial corrections. It also reflects discussion with OTAQ during June and July. These latter discussions have led to significant deletions:

Engine groups. In accordance with discussions with EPA-OTAQ, the text regarding the applicability of technologies across engine groupings has been removed from the GVP. This decision does not reflect any change in proposed policy, but a decision that determining applicability is an EPA-OTAQ decision that should not be part of the ETV protocol.

Fuels. The text regarding verification of fuels, fuel additives, alternative fuels, and lubricants has been deleted from the protocol due to the decision by EPA-OTAQ to manage the retrofit verification of those technologies without ETV involvement. Because so much work has been done by the technical panel, RTI will, at a later date, issue and post another protocol for fuels. ETV verification will be available under that protocol, if desired.

SCR. The text regarding verification of SCR devices has been deleted. RTI and EPA-OTAQ were both concerned regarding the inadequate level of experience on the TP and depth of review the SCR section of the GVP had received. We propose to develop a protocol for SCR, but will augment the TP before doing so. The changes may well be minor, but the ETV comfort level will be improved.

Non-independent test laboratories. As will be discussed by EPA-OTAQ at the meeting, the proposed verification submittal and flow for the VRP offers engine manufacturers a non-ETV route to verification. Engine manufacturers are expected to follow that option, which does not require the added QA of the ETV process. The protocol has been revised to require that ETV verification testing be conducted at independent laboratories, as is normal in the program, and no longer includes the alternative procedure that was included in Draft 4, section 11.2.

At the behest of EPA-OTAQ, PM soluble organic fraction (SOF) and CO_2 were added to the protocol as ancillary measurements whose measurement technique will be stated in the test/QA plan. The description of the statistical techniques has been clarified (I hope). Appendix B was added to illustrate the minimum test calculation procedure, and Appendix C is a sensitivity calculation that explores levels of test error that were not included in Tables 1 and 2, per the EMA request.

The final addition was some text to the beginning of Section 5.1.1 and Section 8.0 to the effect that the minimum number of tests will be re-evaluated as data becomes available during a verification. That is, that more tests may be required before a verification statement is issued if a technology is not found to have as much emission reduction as was stated in the technology application. The same procedure will be used to compute the number of tests required, but the measured emissions reduction (instead of the reduction listed in the application) will be used to make that calculation.

I have also received a number of suggestions regarding the verification statement, including inclusion of a "bottom line box" on the first page and a number of other types of information – warranty, engine / technology interactions, certification standards on the original engine, additional contact information, for example. These changes were not all made in order to get the draft distributed today.

If you have any questions or comments, please contact me at (919) 541-6785 or dwv@rti.org.

GENERIC VERIFICATION PROTOCOL FOR DIESEL OXIDATION CATALYSTS, PARTICULATE FILTERS, AND ENGINE MODIFICATION CONTROL TECHNOLOGIES FOR HIGHWAY AND NONROAD USE DIESEL ENGINES

EPA Cooperative Agreement No. CR826152-01-3
RTI Project No. 93U-7012-015

Technical Panel Draft No. 5

Prepared by:

Research Triangle Institute

APPROVED BY:

RTI Program Director: J. R. Farmer ______________________ Date:____________

RTI Quality Manager: R. S. Wright ______________________ Date:____________

RTI Task Leader: D. W. VanOsdell ____________________ Date:____________

RTI Quality Leader: C. E. Tatsch ______________________ Date:____________

EPA Project Manager: T. G. Brna ______________________ Date:____________

EPA Quality Manager: P. W. Groff ______________________ Date:____________

Table of Contents

1.0 INTRODUCTION

1.1 Environmental Technology Verification

The U.S. Environmental Protection Agency (EPA), through the Office of Research and Development (EPA-ORD) has instituted the Environmental Technology Verification (ETV) Program to verify the performance of innovative and improved technical solutions to problems that threaten human health or the environment. EPA created the ETV Program to substantially accelerate the entrance of new and improved environmental technologies into the domestic and international marketplaces. It is a voluntary, non-regulatory program. Its goal is to verify the environmental performance characteristics of commercial-ready technologies through the evaluation of objective and quality-assured data so that potential purchasers and permitters are provided with an independent and credible assessment of what they are buying and permitting.

The ETV program does not conduct technology research or development. Verification test results are always publically available, and the applicants are strongly encouraged to ensure, prior to beginning a verification test, that they are satisfied with the performance of their technology. Within ETV, this state of development is characterized as “commercial-ready”, and the verification test is conducted on production units or prototypes having the major characteristics of commercial units.

The provision of high-quality performance data on fully-developed commercial technology encourages more rapid implementation of those technologies and consequent protection of the environment with better and less expensive approaches. The ETV Program is conducted by 6 verification centers that span the breadth of environmental technologies.

1.2 Air Pollution Control Technology Verification Center

EPA’s verification partner in the Air Pollution Control Technology Verification Center (APCTVC) is Research Triangle Institute (RTI), a non-profit contract research organization with headquarters in Research Triangle Park, NC. The APCTVC verifies the performance of commercial-ready technologies used to control air pollutant emissions. The emphasis of the APCTVC is currently on technologies for controlling particulate matter, volatile organic compounds, nitrogen oxides (NO_x), and hazardous air pollutants from both mobile and stationary sources. The activities of the APCTVC are conducted with the assistance of stakeholders from various interested parties. Overall APCTVC guidance is provided by the Stakeholders Advisory Committee (SAC), while the detailed development of individual technology verification protocols is conducted with input from Technical Panels (TP) focused on each technology area.

The APCTVC develops generic verification protocols and specific test/quality assurance (test/QA) plans, conducts independent testing of technologies, and prepares verification test reports and statements for broad dissemination. Testing costs are ultimately borne by the technology applicants, although initial tests within a given technology area may be partially supported with government funds.

1.3 Mobile Sources Air Pollution Control Technologies

Control of emissions from mobile sources continues to be of great national importance. Several areas of the country are not able to attain ambient air quality standards. The mobile source provisions of the 1990 Clean Air Act Amendments (CAAA) are intended to reduce most vehicle-related air pollutants by more than 40 percent for 1996 and later model year vehicles and engines. Earlier engine models emit pollutants at higher levels, and as these engine are durable and have long useful lives, they will continue to emit pollutants at higher levels many years into the future. For these reasons, the EPA funded and the APCTVC SAC recommended inclusion of air pollution control technologies for mobile sources as a priority for verification.

One important group of mobile source air pollution control initiatives is concerned with highway and nonroad use diesel engines. The diesel particulate standard for urban buses was reduced in 1993 by 60 percent, from 0.33 to 0.13 g/kWh (0.25 to 0.10 g/bhp-hr). The standard, which applies to urban transit buses, dropped to 0.094 g/kWh (0.07 g/bhp-hr) in 1994 and to 0.067 g/kWh (0.05 g/bhp-hr) in 1996. While existing engine technologies can meet these standards, future standards are expected to be increasingly stringent and will require the use of post-combustion emissions control technologies. New technologies are being developed to meet these goals. In addition, since a NO_x emission level below the level mandated allows the generation of credits through the Voluntary Retrofit Program (VRP), pollution prevention becomes more cost effective, and innovations in less-polluting alternatives and control technologies are encouraged.

Retrofit mobile source control technologies are principally exhaust treatment emission control devices and engine modifications. Some require no mechanical changes to engines, while others will involve some modification of the engine or its control system.

Filters for particulate matter (PM) control and diesel oxidation catalysts (DOC) may make use of or require some integration with engines. Engine modifications, in the context of this protocol, refer to pollution reduction technologies integral to the engine or the engine control systems. All these technologies have the potential to affect engine performance, and the concurrence of the engine manufacturer that the changes are compatible with safe, efficient, and reliable operation in the engine is an important element in demonstrating commercial readiness and suitability for verification. The technologies and their testing are discussed in more detail below.

SCR NOx control technologies, fuels, fuel additives, reformulated fuels, and lubricants are specifically excluded from consideration under this protocol for testing as retrofit emissions control devices. Protocols for these technologies will be developed in the future.

1.4 The APCTVC Mobile Sources Verification Program

This generic verification protocol (GVP) provides the requirements for APCTVC verification of the performance of diesel oxidation catalyst, PM filters, and engine modification air pollution control technologies applied to highway and nonroad use diesel engines. Other technologies will be addressed similarly. Other organizations (e.g., EPA’s Office of Transportation and Air Quality (EPA-OTAQ) and the California Air Resources Board) also ‘verify’ the performance of mobile source emissions control devices under different protocols to meet the needs of those organizations. Specifically, EPA-OTAQ has established, for engine manufacturers whose internal test laboratories certify diesel engine emissions, a generally parallel path that does not require the level of external QA that is required for APCTVC verification. The technology applicant should discuss the intended application of the technology with the appropriate regulatory body to determine the most suitable path for verification.

The GVP is intended to apply only to diesel oxidation catalysts, PM filters, and engine modifications and their combinations. The APCTVC reserves the right to evaluate each technology submitted for verification and to determine the applicability of this protocol to that specific technology. Special testing may be required in some cases to maintain the integrity and credibility, and therefore value of verifications. The critical data quality objectives (DQOs) in this document were chosen to provide emissions measurements sufficient to support the diesel engine VRP and its emissions credit provisions. Emissions credit allowances will be set by the appropriate state regulatory authority or the EPA OTAQ. (As stated above, the VRP approving agencies may have data requirements that are in addition to the ETV test report.)

This protocol was developed and has been reviewed by a technical panel composed of a broad group of stakeholders who have expertise in mobile source controls and come from the vendor, user, and regulatory spheres. Technical panel membership is dynamic, and its composition is expected to change over several years as technical emphases change. The APCTVC will maintain membership balance on the panel.

The basic APCTVC verification test will measure and report baseline emissions concentrations and rates for an engine prior to use of the retrofit technology and also the emissions concentrations and rates for this engine following retrofit. It will be conducted at an independent, third-party test laboratory. The data quality requirements of this generic protocol will be applied at specific test laboratories for specific types of technologies through the preparation of specific test/QA plans. Other laboratory-, application-, or technology-specific information may also need to be addressed in the test/QA plan, which is described in Section 10.0. In general, test/QA plans prepared by test laboratories will not be reviewed by the entire technical panel. However, because specific technology areas may require special expertise or emphasis, input and review will be obtained from an ad hoc subcommittee of the technical panel and/or outside experts when deemed appropriate by the APCTVC. Test results will be presented as verification reports and verification statements.

1.5 Quality Management Documents

Management and testing in this ETV program are performed in accordance with procedures and protocols defined by the following:

1) EPA's ETV Quality and Management Plan (ETV QMP) (EPA, 1998a or the quality management plan current at time of testing),
2) the APCT Quality Management Plan (QMP) (RTI, 1998),
3) the Generic Verification Protocol for Verification of Retrofit Air Pollution Control Technologies for Highway and Nonroad Use Diesel Engines (this document), and

4) The Test/QA plan prepared for each specific test or group of tests.

EPA's ETV QMP lays out the definitions, procedures, processes, inter-organizational relationships, and outputs that will ensure the quality of both the data and the programmatic elements of the ETV Program. Part A of the ETV QMP contains the specifications and guidelines that are applicable to common or routine quality management functions and activities necessary to support the ETV Program. Part B of the ETV QMP contains the specifications and guidelines that apply to test-specific environmental activities involving the generation, collection, analysis, evaluation, and reporting of test data.

APCT's QMP describes the quality systems in place for the overall APCTVC. It was prepared by RTI and approved by EPA. Among other quality management items, it defines what must be covered in the GVPs and test/QA plans for technologies undergoing verification testing.

Generic Verification Protocols are prepared to describe the general procedures to be used for testing a type of technology and define the critical data quality objectives (critical DQOs). The GVP for retrofit air pollution control technologies for highway and nonroad use diesel engines was written by the APCTVC with input from a technical panel and approved by EPA.

A test/QA plan is prepared for each test or group of tests. Because multiple testing organizations will be conducting the tests and the desirability to ensure comparability, the APCTVC will develop a prototype test/QA plan (not part of this GVP) for each type of technology. This prototype will be customized by the testing organization to meet its specific testing arrangements subject to approval by the APCTVC and EPA-ORD. However, modifications that the APCTVC feels will compromise comparability between labs will not be approved. The test/QA plan describes, in detail, how the testing organization will implement and meet the requirements of the GVP. The test/QA plan also sets DQOs for any planned measurements that were not set in the GVP. The test/QA plan addresses issues such as the test organization's management structure, the test schedule, test procedures and documentation, analytical methods, record keeping requirements, and instrument calibration and traceability, and it specifies the QA and quality control (QC) requirements for obtaining verification data of sufficient quantity and quality to satisfy the DQOs of the generic verification protocol. Section 10 of this GVP addresses requirements for the test/QA plan.

2.0 OBJECTIVE AND SCOPE

2.1 Objective

The objective of this GVP is to establish the parameters within which diesel oxidation catalysts, PM filters, and engine modification air pollution control technologies for highway and nonroad use diesel engines will be tested to verify their performance with uniform and consistent methodologies within the APCTVC. The protocol addresses the requirements for technology submission, outlines the test conditions and procedures to be used, and states the critical data quality objectives for verification and states reporting requirements. The control technologies will be verified within a specified range of applicability, and verification reports and statements will be produced for dissemination to the public.

2.2 Scope

APCTVC testing will be performed to quantify the effectiveness of commercially ready emissions control technologies that are intended for use on diesel engines considered mobile sources of air pollutants. Emissions testing under this verification program is based on the applicable Federal Test Procedures (FTPs), 40 CFR Part 86 for highway engines and 40 CFR Part 89 for nonroad engines. As performed by manufacturers to certify their engines, FTPs are fully defined by the regulations, and consist of the engine-appropriate cold- and hot-start engine dynamometer tests conducted under specified load cycles. For purposes of this protocol, the number and type of FTP tests may be different from certification requirements, as determined by the applicant and the APCT VC to best verify the performance of the technology under consideration. However, the individual FTP test modules -- the cold-start test or the hot-start test -- will be performed completely in accordance with the regulations. (The low NOx and PM emissions from post-2001 engines are prompting development of new test procedures better suited to these emission levels. As these test procedures become standardized and acceptable to the EPA, they will be acceptable for use in verifications.) The pollutants of major interest are nitrogen oxides (NO_x), hydrocarbons (HC), particulate matter (PM), and carbon monoxide (CO). Other measurements will also be made of emissions (for instance, CO_2) and operating parameters of the test engine and the control technology. Additional measurements may also be required if the technology might be reasonably expected to generate secondary emissions. Emissions will be measured along with other data useful for evaluating the performance of the technologies and the technologies' associated environmental and efficiency impacts. In this context, the effects of control technologies on fuel economy and engine performance and power will be of particular interest.

Also fundamental to this verification protocol is providing emissions control efficiency information needed for applicants to participate in the EPA Voluntary Diesel Retrofit Program (VRP). The VRP is managed by EPA-OTAQ. The data quality objectives given in Section 2.3 were set to provide emissions control device performance data that can be used in submittals to the VRP. VRP determinations are made by EPA-OTAQ, which may require information not included in the verification.

The APCTVC will consider applications for verification of air pollution control technologies on particular engines specified and provided by the applicant. Depending on the expected application, the data collected and the test design, the verification obtained may be valid to only that single engine or to groupings of multiple engines. If application of a single engine test result to an engine group is made by the regulatory body, the decision will be based on an expectation that the control device, if appropriately sized, will perform similarly on all the engines in that group. Generally, similar emissions control performance is expected from engines that have the same engine technology and use. The sensitivity of emissions control performance to engine type and usage is not known to be the same for all technologies, and applicability decision will be made separately for each technology type and possibly for each technology. Previously obtained performance data may enter the decision. In all cases, the decision regarding applicability will be made by EPA-OTAQ, which should be contacted at the time verification is contemplated for current information.

Implicit in the potential use of single engine verification tests as predictive of performance over segments of the total engine population is the availability of non-proprietary basic design information (e.g., space velocity, catalyst loading) to the APCTVC and the potential technology user to evaluate proper scaling between engines. Alternatively, an applicant whose technology is being sold in fixed incremental sizes with published ranges of applicability (e.g., model AAA is suitable for 100 to 150 hp engines) will be tested on an engine at the most challenging end of the range of applicability. Verification reports and statements will report the results and the design guidance required to independently extend application of the technology to other engines in the same engine grouping.

To request verification, the applicant applies to the APCTVC for the technology to be tested and proposes the test engine(s) to be used. The APCTVC will review the application and provide input as required to ensure that the engine(s) proposed are suitable, that the emission control equipment sizing is correct, and that the engine(s) manufacturer accepts application of the emission control technology to the engine. The equipment/technology will be applied to the engine(s) according to the applicant’s instructions. Verification test results for the engines will be reported in the verification reports and statements. The results will provide the emissions performance data required for the VRP reviewing regulatory authority to determine the emission reduction capability of the technology.

2.2.1 Highway Engines

Applicants may choose to have their technologies verified on a single highway engine or multiple selected engines, depending on the applicants intended use of the data. EPA-OTAQ will determine the extent of applicability of data from any given engine, and should be consulted by the applicant for that purpose. Testing of emissions control technology intended to control emissions from highway diesel engines will be conducted generally under the provisions of 40 CFR, part 86, subpart N. The primary emissions measurements will be of NOx, PM, HC, CO, and other FTP requirements. CO_2 and the engine operating parameters are required secondary measurements. Each engine in the test will be loaded by a dynamometer as described in the transient Federal Test Procedure (FTP). Each verification test will consist of at least a single full FTP test (cold- and hot-start) on an emission-stabilized baseline engine and the engine with the control technology in use. Additional hot-start tests may also be required to meet the minimum number of test requirements described in Section 5.1, or the applicant may wish to run additional tests to narrow the confidence interval on the result. (An ETV requirement for multiple hot-start tests may be met using the hot-start results from full FTP test data (both cold- and hot-start), at the applicants option.) Durability testing , which consists of verification of aged control technology units as described in Section 5.2.9, is part of the verification process. Emissions reductions will be computed relative to the baseline engine emissions.

2.2.2 Nonroad Engines

As with highway engines, applicants select the nonroad engines on which to test their technologies. The verification testing of emissions from nonroad diesel engines will be conducted generally within the requirements of 40 CFR, part 89, subpart E. As for highway engines, the primary emissions measurements for nonroad engines will be of NO_x, PM, HC, CO, and other FTP-requirements. CO_2 and engine operating parameters are required secondary measurements. The verification testing will consist of single or multiple nonroad steady-state mode tests (40 CFR, part 89, subparts D and E), as described in Section 5.0. (Concerns about transient emissions from nonroad engines are prompting development of new test procedures. As these test procedures become standardized and are codified in the FTP, they will included in the ETV test protocol. The test must be conducted over all applicable modes of the test cycle appropriate to the engine (e.g., 8-mode test cycle for variable speed engines or 5-mode cycle for constant speed engines) or may be conducted over all modes at the applicant's request. The VR will reflect the extent of the test conducted. Each verification test will consist of the same assemblage of FTP tests on the broken-in baseline engine and the engine with the control technology in use. Durability testing is required as described in Section 5.2.9. Composite emissions reductions are computed relative to the baseline engine emissions. In addition, the emissions results will be reported in composite and mode-by-mode to allow flexibility in use of the data for different engine applications.

2.2.3 Control Technologies

This GVP is specifically intended to include the following emissions control technologies:

1) active and passive after-treatment diesel oxidation catalysts,
2) PM filters, and
3) engine modifications.

The basic verification test remains the same for all emissions control technologies. However, the technologies interact differently with the various engine technologies. Therefore, the engine grouping concept may be applied differently by EPA-OTAQ depending of the nature of the technology. In addition, where technologies require particular fuel characteristics or have other restrictions or interactions, applicants must specify these and any associated requirements in their ETV applications.

2.2.4 Relationship of ETV program to EPA-OTAQ VRP Verification

EPA-OTAQ has established a generally parallel verification path, not applicable to all applications, that does not require the level of external QA that is required for APCTVC ETV verification. The technology applicant should discuss the intended application of the technology with EPA-OTAQ to determine the most suitable path for verification. As of the date of this protocol, emissions test data from a full FTP test (whether highway or nonroad), that was generated by a manufacturer to obtain a certificate of conformity, may be determined by EPA-OTAQ to constitute a valid data set for VRP purposes for particular engine families to which the certification applies. Certification data do not pass though the ETV verification program. The certification and VRP verification processes are independently performed by EPA-OTAQ.

2.3 Data Quality Objectives (DQOs)

The data of primary interest in this verification are the reduction in emissions of NO_x, HC, PM, and CO. (Numerous other measurements, including CO_2 emissions, will also be made, as described in later sections. However, these are not considered critical, and the methods and data quality objectives will be stated in the test/QA plan for each technology.) The DQOs of this GVP are met by meeting the requirements of the test methods specified in 40CFR Parts 86 or 89 for highway or nonroad diesel engines, respectively, while conducting the number and type of FTP tests called for by the approved test/QA plan for the technology. Verification tests that do not meet the FTP QA requirements must be repeated.

The number of and type of FTP tests (cold- and/or hot-start) required is dependent on the expected emissions reduction, the desired confidence interval on the results, and measurement variability. Statistical test design procedures are utilized to produce, from these inputs, a test/QA plan that provides verification data adequate for the purpose at minimum cost. At a fixed measurement variability, the fewest number of tests will be required when the expected emissions reductions are large and a narrow 95% confidence interval on the result is not required by the applicant. On the other hand, verification of small emissions reductions with high accuracy (narrow confidence intervals) will require the largest numbers of tests, also at fixed measurement variability. This is a consequence of applying standard statistical test design procedures. All verification test/QA plans must include sufficient tests to have a 90% probability of detecting the expected emissions reductions, when computed using the expected experimental errors for the various measurements. The procedure to determine the appropriate number of tests is given in Section 5.

An applicant may conduct privately sponsored tests at a test laboratory for development purposes with the same test engine prior to and/or after conducting ETV tests. Such testing is understood to be common and important to ensure the technology is properly adjusted and tuned to the application. However, two important principles of ETV are that verified equipment be commercial ready when tested and that all data obtained under the verification process be reported.

Therefore, preparation for the ETV test (submittal of the technology to the APCTVC, discussion of engine selection and preparation of the test/QA plan) must be completed prior to conducting the ETV test itself. In particular, declaration of the test run which is to be the ETV test must be made prior to starting the test, the engine must be brought to a starting point in accordance with the test/QA plan, and the results of that test will be documented and reported in accordance with the test/QA plan. The data from all ETV tests will be retained and reported to the APCT VC, including invalid FTP test results. Data that meet the QA requirements of the FTP are considered valid and will be used to compute emissions reductions for verification purposes. Section 8.0 addresses a technology applicant's options should the technology perform below expectations.

Verification tests conducted at qualified laboratories which meet the requirements of this GVP will be accepted as verification tests by the APCTVC. This will require that the technology be submitted to the APCTVC and that a test/QA plan be prepared and approved prior to conducting the test. All QA requirements of the FTP methods must be met, and the test and test laboratory must meet the QA requirements of the ETV program as established in this protocol and the test/QA plan.

Engine emissions are expressed in grams of pollutant per kilowatt-hour (g/kWh), with English engineering units of grams per brake horsepower-hour (g/bhp-hr). The primary measurement of HC and NO_x is normally concentration in the exhaust stream in parts per million by volume (ppmv), which is then converted to g/kWh in accordance with the FTP. For calculation of the technology's removal efficiency, the baseline emissions of the tested engine must also be known. The control technology performance will be reported as both absolute emissions in g/kWh and as percentage emissions reduction for a specific engine or engine family. The percentage emission reduction reported will be the mean emission reduction (relative to the baseline emission) with attendant upper and lower 95% confidence limits on that mean.

3.0 VERIFICATION TESTING RESPONSIBILITIES

This verification testing program is conducted by the APCTVC under the sponsorship of the EPA-ORD and with the participation of technology applicants. The APCTVC is operated under a cooperative agreement by the Research Triangle Institute (RTI), EPA's ETV verification partner. RTI's role as verification partner is to provide technical and administrative leadership and either conduct or manage the conduct of verification testing and reporting. Various subcontractors have roles in the APCTVC under RTI's management.

Verification tests are conducted by qualified test laboratories as contractors to RTI's APCTVC.. Test laboratory-specific verification test/QA plans are prepared by the testing laboratories to meet the requirements of the approved generic verification protocol..

The test/QA plan includes a chart that presents the test program organization and major lines of communication. The organizations involved in the verification of mobile diesel engine air pollution control technologies are the EPA, RTI, testing laboratory, and technology applicant.

The primary responsibilities for each organization involved in the test program are:

1) The EPA-ORD, following its procedures for ETV, reviews and approves GVPs, test/QA plans, verification reports, and verification statements, and conducts QA audits.
2) The APCTVC prepares the GVP, provides oversight of the testing organization, provides a template for test/QA plans, and jointly with EPA-ORD reviews and approves the

verification test reports and verification statements.

3) The testing organization prepares the test/QA plan in accordance with the GVP, coordinates test details and schedules with the applicants, conducts the tests, and prepares and revises draft verification test reports and draft verification statements. The testing organization QA staff is responsible for conducting internal QA on test results and reports.
4) EPA-ORD and/or APCTVC QA staff, at their discretion, will conduct assessments of the test organization's technical and quality systems.
5) The technology applicants provide complete, commercial-ready equipment for verification testing; provide logistical and technical support, as required; and assist the testing organization with operation and monitoring of the equipment during the verification testing. The applicants responsibilities are defined by a contract or letter of agreement with RTI as the APCTVC manager.

4.0 TECHNOLOGY CAPABILITIES AND DESCRIPTION

This section outlines the information to be submitted by the verification applicant, who is the basic source of the information regarding the mobile source air pollution control technology. This information is used by the test laboratory and APCTVC to prepare and review a test/QA plan that meets the requirements of the applicant and potential users of the verification. No general outline can anticipate the data requirements for all possible technologies, so the applicant may be requested to supplement this outline when additional information is need. This protocol has been developed with an awareness of the California Air Resources Board (CARB) verification program, and an application to CARB for retrofit verification is expected to provide adequate information.

The verification test/QA plan will summarize this information in a form that clearly describes the technology being verified and states, for potential users of the technology, it's intended range of applicability as stated by the applicant. The test/QA plan will also include a draft verification statement, based on Appendix A, customized to the specific technology being verified and measurements being made.

4.1 Basic Technology Identification and Verification Requirements

The basic technology identification should be a concise description of the technology that describes what is being verified and summarizes the emissions control performance expected. This information will be used to describe the technology in the verification statement.

It should include such information as: technology name, model number, manufacturers' name and address, serial number or other unique identification, warning and caution statements, capacity or throughput rate, specific installation instructions, adjustments, limits on flow, temperature, pressure, and other information necessary to describe the specific technology and its intended use. Warranty information on the technology should be provided, including a sample warranty statement.

In addition, the applicant must state the goal of the verification in terms of range of applicability (single or multiple engine, fuel requirements, equipment sizing, etc.), expected emissions reduction, and anticipated data use. This information will be used to develop the test/QA plan for verification.

4.2 Technology Descriptive Information

This section of the application is intended to describe the technology more fully. It will be used to prepare the test/QA plan and as a more complete description of the technology in the verification report.

The applicant should describe the operation of the technology in a brief (300 word) statement, referring to the scientific principles of that operation. When applicable, the inclusion of schematic drawings explaining operation of the technology is encouraged. Examples of descriptive information that should be included are:

<u>Installation requirements</u>. Space occupied, installation time, any physical modifications, placement issues, identification of ancillary equipment, if any, recommended duration of degreening as well as any special start-up procedures, and any other special requirements.
<u>Operation</u>. This description should include identification of any favorable or unfavorable operating conditions and their effect on performance, fuel requirements (such as fuel sulfur limit), consequences of misfueling, identification of any chemicals or other consumable reactants, regeneration requirements, and expected engine back-pressure. Any requirement for energy sources (e.g., heat, electricity, compressed air, hydraulic fluid, pressure) external to the engine must be identified so they can be accounted for in the test/QA plan.
<u>Maintenance and warranty</u>. Identification of recommended maintenance procedures, cleaning instructions, and spare parts and supplies. Statement concerning the warranty being offered.
<u>Operator or mechanic qualifications/training/safety</u>. Qualifications needed to operate and service the technology, amount and type of training needed for operation and maintenance, special safety considerations, and recommended safety considerations and precautions. Use of personal protective equipment (eyeglasses, hearing protection, etc.)
<u>Secondary emissions</u>. Identification of any secondary emission to the air that impacts water quality, or liquid or solid waste.
<u>Technology's life expectancy</u>.

Special attention should be given to the technology's regeneration requirements, if any, including a description of the regeneration process, any operating condition requirements for successful regeneration (e.g., temperature), and any manual or computer control of regeneration.

In the case of combinations of independent technologies that are being submitted for verification, the description of the combined technology should completely identify and describe those technologies being combined and fully state the nature of the combined test and expected result.

4.3 Technology Performance

The technology applicant must quantify the performance expected from the technology and support that expectation with background test data, including both initial performance and technology durability test descriptions and results. In general, these data will not be used to verify the performance of the technology, but will be used to develop a verification test/QA plan that can adequately support the expected performance. The level of detail required of the description of existing tests and their results cannot be generally stated because it is dependant on the verification goals. Applicants are encouraged to supply pertinent data supporting their claims, which will include descriptions of the test facility, procedure, quality assurance and control, and any deviations from the FTP.

All aspects of technology performance should be addressed, beginning with performance during routine steady-state operation, but also including unsteady or unfavorable operation such as extended idling periods, uncontrolled regeneration, in-place maintenance, etc. Any known or expected impact the technology might have on the character of the emissions (gas composition, temperature, particle size or composition, etc.) should be identified.

4.4 Technology / Engine Interactions

The applicant must describe interactions between the proposed engine(s) and the technology, to include the known or expected effects of the technology on the engine(s). Backpressure, additional parasitic loads, fuel consumption, effects on engine durability, and oil consumption are of special concern. The relationship of the technology, engine control logic, and engine operation should be addressed for the engine(s) under consideration.

The applicant should defend the applicability of the technology to the applicable engine(s) by including exhaust temperature profiles, duty cycles, and other relevant performance information. The operating conditions that are favorable for the control technology should be compared with those of the engine.

The opinion of the engine(s) manufacturers regarding compatibility of the technology with their engine should be solicited, summarized, and the correspondence included in the application. Any known or anticipated impact of the technology on engine warranty is to be identified. The relationship between technology warranty and engine warranty should be discussed.

5.0 VERIFICATION TESTING

Sections 5.1 and 5.2 present general verification test considerations that apply to most retrofit air pollution control technologies. The remaining sections of this chapter are specific to the indicated types of technologies.

5.1 Verification Test Design

The number of tests required for a verification test is dependent on the expected emissions reduction, the desired confidence interval on the results, and the measurement variability. The first two items are described in the verification application, and estimates of the later may be obtained from experience with the test method. Statistical test design procedures and historical experimental variability data are used to design a test to meet these requirements. In general, the fewest number of tests will be required when, for a fixed measurement variability, the expected emissions reductions are large and a wide confidence interval on the result can be accepted. On the other hand, for a fixed measurement variability, verification of small emissions reductions with high accuracy (narrow confidence intervals) will require a large number of tests.

All ETV verifications will include 1 full FTP test plus additional tests as required to satisfy the requirements stated in Section 5.1.1 or the requirements of the applicant for narrow confidence intervals about the mean. For highway engines, this single test will include both the cold-start and the hot-start portions of the transient FTP, and additional tests will be hot-start tests (which may be obtained alone or as part of full FTP tests, at the applicants option.) For nonroad engines, testing will be conducted using the appropriate nonroad test sequence (i.e, 8-mode test for applicable engines, 5-mode test for constant speed engines, 6-mode test for variable speed engines under 19 kW) for the engine classification for which the technology is intended. The applicant may elect to conduct additional modes so that the emissions data can be composited for multiple engine classifications.

5.1.1 Determination of Minimum Number of Tests

Minimizing the cost of verification testing is important, and reducing the number of tests conducted is one way to minimize cost. However, if too few tests are conducted, normal experimental variability could prevent the verification from producing a useful outcome. For measurements having known variability, and for stated expected reductions in emissions, the probability that a given number of tests can detect the expected reduction can be computed from statistical theory based on normal distributions.

This verification protocol requires that all verification test/QA plans include sufficient tests to have a 95% confidence that there is a 90% probability of detecting the expected emissions reductions, as computed using the expected experimental variability for the various measurements. For highway engines, the replicate tests will be hot-start tests. For nonroad engines, the complete multimode test sequence must be replicated.

As will be made clear below, successful use of the minimum test calculation requires that the technology applicant present a realistic estimate of the emissions reduction. The test laboratory will compute the emission reduction for the initial test and will recompute the minimum number of tests given the actual emissions reduction. If the measured emissions reduction exceeds the estimate, the verification will proceed to completion as planned. However, if the measured emissions reduction is less than the applicant’s estimate, and the number of tests required to meet the ETV minimum requirements is greater than planned, the test laboratory will contact the applicant as soon as practical regarding the need for additional tests, at the applicants expense. Failure to have sufficient tests will prevent completion of the verification, and the results of the verification will be publically issued only as a verification report.
In the paragraphs below, the results of applying the procedure are first illustrated by two tables, followed by a description of the procedure itself. A step-by-step example of the calculation is presented in Appendix B. An sensitivity analysis of the results of using the procedure for a range of measurement variability is given in Appendix C.

The results of the calculation are illustrated in Tables 1 and 2 for PM and NO_x emission reductions, respectively. In Tables 1 and 2 the baseline engine is assumed to be at a fixed emission value having a known measurement standard deviation. Installing the control technology gives emissions reductions of 5%, 20%, 50%, and 85%. The row labeled “Measurement variability at specified emission reduction” is an expected measurement variability for PM (Table 1) or NO_x (Table 2). (Variability is expressed as standard deviation divided by the corresponding baseline engine mean emission, multiplied by 100%.) This variability increases as the expected emission reduction increases because the absolute error is roughly constant, though the magnitude of the emission is decreasing. The “variability values” in Tables 1 and 2 are based on experience at a single commercial test laboratory (Ullman, 2001) for replicate hot-start tests on a single engine in a well-controlled test. They are included in this GVP only as illustrations of the amount of variability expected. Measurement variability may be different for different engines, test sequences, and test laboratories.

Table 1 indicates that 2% baseline engine variability can be achieved for replicate hot start NOx and PM measurements at normal emissions levels. Further afield, for HC emissions at the lower absolute levels, the variability may be on the order of 30%. No estimate of variability was possible for a NO_x reduction of 85%, as shown by the NA symbol in Table 1. In the development of the test/QA plan, the test laboratory will make an estimate of expected variability and calculate the expected number of tests required. As stated earlier, the number of required tests maybe re-evaluated after the initial tests have been conducted.

In both tables, the emissions measurements are assumed to be distributed normally and to have known standard deviations. The “Probability of Detecting ...” column is the probability of detecting the specified emission reduction (expressed as a percent difference in the mean emission for the baseline engine and the controlled engine relative to the baseline engine) at the 95% confidence level, using a one-sided test with the given measurement variability (expressed

Table 1. **Number of replicate tests (on both baseline and controlled engine) to achieve a high probability of detecting a PM emission reduction at a confidence level of 95%**

	PM Emission Reduction Relative to 0.804 g/kWh (0.6 g/bhp-h)			
	5%	**20%**	**50%**	**85%**
Measurement variability at specified emission reduction	2%	2%	3%	10%
Meas. variability for baseline engine (at 0.804 g/kWh PM emission)	2%	2%	2%	2%
Probability of detecting stated emission reduction at 95% confidence level	**Number of tests required to meet probability and confidence requirements**			
80%	2	1	1	1
90% (ETV Minimum Probability)	3	1	1	1
95%	4	1	1	1

as a percentage of the cert value for the baseline engine and a percentage of the reduction from the cert value for the controlled engine) and indicated number of tests.

For example, in Table 2, the value in the first row and first column indicates that, with two baseline tests and two controlled engine tests, there is a 95% confidence that the probability of detecting at least a 5% emissions reduction, relative to the baseline engine, will be 80%. Moving down that column shows that increasing the probability of detecting the 5% emission reduction to 95% would require that 4 baseline and 4 controlled engine tests be conducted.

Table 2. **Number of replicate tests (on both baseline and controlled engine) to achieve a high probability of detecting a NO_x emission reduction at a confidence level of 95%**

	NO_x emission reduction relative to 8.04 g/kWh (6.0 g/bhp-h)			
	5%	20%	50%	85%
Measurement variability at specified emission reduction	2%	3%	7%	NA
Meas. variability for baseline engine (at 8.04 g/kWh NO_x emission)	2%	2%	2%	2%
Probability of detecting stated emission reduction at 95% confidence level	**Number of tests required to meet probability and confidence requirements**			
80%	2	1	1	NA
90% (ETV Minimum Probability)	3	1	1	NA
95%	4	1	1	NA

NA = estimate of variability not available

In both tables, for most occasions the required number of replicate tests is equal to one. These examples indicate that a single test of the baseline can be compared to a single test of the controlled engine with a high probability of detecting the emission reduction, provided the measurement standard deviations are truly the values shown in the tables and the distribution of the emissions reductions is truly normal. In these instances, the emissions reductions are so large that they are easily detected. For example, the value in the second column and second row of Table 2 indicates that a single baseline test and a single controlled engine test can be run with a 95% confidence that the probability of detecting a 20% emissions reduction from the baseline engine will be 90%.

For test design purposes, the standard deviations in Tables 1 and 2 are to be used to establish the minimum number of tests required for verification of PM and NO_x control technologies. The procedure used is illustrated with examples in Appendix B, and is described below.

Assume there are two normal distributions, one for the baseline-engine emissions data and one for the controlled-engine emissions data, and that these distributions have variances equal to σ^2_1 and σ^2_2. A sample of data will be taken from each distribution and a one-tailed two-sample z-test will be run in order to compare the two means of these two distributions. The required sample size needed in each of the two samples is given by:

$$n \approx (z_\alpha + z_\beta)^2 (\sigma^2_1 + (1 - \delta/100)^2 \cdot \sigma^2_2) / \delta^2$$

where

- n = sample size in each group
- δ = difference in emissions mean (expressed as a percent of the cert value)
- σ^2_1 = squared standard deviation of baseline-engine data (expressed as a percent of the cert value)
- σ^2_2 = squared standard deviation of controlled-engine data (expressed as a percent of the cert value)
- $1 - \alpha$ = confidence coefficient (e.g., 0.95)
- $1 - \beta$ = probability of detection of reduction (e.g., 0.90)
- z_α = normal distribution value corresponding to upper-tail probability of α
- z_β = normal distribution value corresponding to upper-tail probability of β

Note that, in order to use the above formula, all standard deviations and emissions reductions must be expressed in terms of a percentage of a fixed baseline emission value, which for Tables 1 and 2 was chosen to be the appropriate (PM or NO_x) certification value. For example, in row 1 and column 1 of Table 1, the percent reduction is 5%. The standard deviation of the controlled-engine emissions would be (.02)(.95)*100%=1.9%, and the standard deviation of the baseline-engine emissions would be 2%.

5.1.2 Confidence Interval on the Verification Result

Another consequence of measurement variability is that the mean of a small number of measurements has a small probability of giving the true emission reduction. (As stated in section 5.1.1, in some cases it may not be possible to make any statistically-significant determination that there was any emission reduction.) When sufficient tests are available, the results of verification tests will be presented as the mean emission reduction for the test and the 95% confidence interval on that mean calculated using the standard deviation measured during the verification test. (For single-test and two-test verifications, the historical standard deviations for the

Table 3. 95% Confidence intervals on mean PM emission reduction relative to baseline emission of 0.80 g/kWh (0.6 g/bhp)

	PM emission reduction relative to 0.80 g/kWh baseline engine emission			
	5%	20%	50%	85%
PM measurement variability for controlled engine	2%	2%	3%	10%
PM measurement variability for baseline engine	2%	2%	2%	2%
Number of verification tests	**95% confidence intervals on emission reduction**			
1	5±5.3%	20±4.4%	50±3.5%	85±3.0%
2	5±3.7%	20±3.1%	50±2.5%	85±2.1%
3	5±3.0%	20±2.6%	50±2.0%	85±1.7%

measurement of interest at the test laboratory will be used to estimate the confidence interval on the mean.) The results are illustrated in Tables 3 and 4.

Table 3 gives the two-sided 95% confidence intervals on the indicated mean percent emissions reduction from a PM emission rate of 0.80 g/kWh (0.6 g/bhp-hr) for the indicated number of baseline and controlled engine tests for four estimates of measurement variability. (As was true in Tables 1 and 2, the measurement variability in Tables 3 and 4 is expressed as the measurement standard deviation divided by the baseline engine mean emission.) In Table 3, the confidence interval in the first row and first column is 5±5.3%. This means that there is 95% confidence that

Table 4. 95% Confidence intervals on mean NO_x emission reduction relative to baseline emission of 8.04 g/kWh (6.0 g/b-hp)

	NOx emission reduction relative to baseline emission of 8.04 g/kWh (6 g/b-hp)			
	5%	20%	50%	85%
NO_x measurement variability for controlled engine	2%	3%	7%	NA
NO_x measurement variability for baseline engine	2%	2%	2%	2%
Number of verification tests	**95% confidence intervals on emission reduction**			
1	5±5.3%	20±5.7%	50±7.1%	NA
2	5±3.7%	20±4.0%	50±5.0%	NA
3	5±3.0%	20±3.3%	50±4.1%	NA

the true mean emission reduction, relative to the baseline engine at 0.80 g/kWh (0.6 g PM/b-hp) and the controlled engine, is between 0 and 10.3% reduction for a single test with the indicated 2% variability. Since the 0% reduction is within the interval, any reduction caused by this hypothetical technology is open to question, even though the single test showed a 5% reduction. This is the outcome predicted by Table 1, which used the same statistical process in a slightly different way. Increasing the number of tests to 3 baseline and 3 controlled engine tests (moving down the column), the 95% confidence interval on the mean reduction is show to be 5% ± 3%, or between 2% and 8% reduction.

Table 4 is similar, but has been computed for a baseline emission of 6.0 g NO_x/b-hp. As another example, the value in the row of confidence interval results for one test and the third column is 50 ± 7.1%. This indicates that the 95% confidence interval for a 50% emission reduction, from a single test, is from 42.9 to 57.1% emissions reduction. Increasing the number of tests (for both baseline and controlled engines) to three, at the same standard deviation, narrows the confidence interval to 45.9 to 54.1%.

Tables 3 and 4 are illustrative. Actual verification tests may have different measurement variability, and the verified emission reduction will have a confidence interval computed from the measurements made during the verification test itself.

5.2 General Verification Test Considerations

Unless specified otherwise, the general test considerations in this section will apply to all technologies.

5.2.1 Submittal of Technologies and Verification Sequence.

The verification process begins with the applicant indicating to the APCTVC or to a test laboratory an interest in the ETV process. In either case, the second step is agreement between the APCTVC, the applicant, and the test laboratory regarding the general form of the verification process and the responsibilities of all parties. This second step culminates with a formal application for verification to the APCTVC, providing the information about the technology described in Section 4. The approximate cost of the verification will be estimated and a contractual relationship between the APCTVC and the applicant will be started.

The test laboratory will then develop the verification test/QA plan, reviewing it with the applicant and the APCTVC to ensure that it meets the requirements of the APCT VC, and, to the extent possible, accomplishes the applicant's goals for verification. The test/QA plan will then be reviewed formally by the APCTVC and EPA. Test/QA plan development consists of a series of sequential activities, and the test/QA plan must be approved before testing begins.

The applicant will provide the technology to be tested and the engine on which to test it. Scheduling of the verification will be done by the test lab. De-greening of the technology is the applicant's responsibility, as is providing a de-greened unit and an aged unit for durability testing. The applicant must provide any special ancillary equipment required for testing.

The applicant may choose to conduct private, proprietary test work at the test lab during the same time period the verification is taking place. Such arrangements are between the test lab and the applicant. However, a clear differentiation is required between such private test work and the verification test itself. In addition, the APCTVC must have adequate notice regarding a verification test to be able to audit those tests if desired. The manner in which the start and end of the verification test will be established and when the APCTVC will be notified must be specified in the test/QA plan. All verification data must be reported.

Following the verification test, the test lab will report the data to the APCTVC, which will incorporate those data into the verification statement and report. The VS/VR will be reviewed with the test lab and the applicant to address comments and concerns as appropriate. The draft report will then be submitted to the multi-step EPA review and revised as needed. The signed verification statement and report will be provided by the APCTVC to the applicant, test laboratory EPA, and posted on the ETV and APCTVC websites.

5.2.2 Highway Engine Verification

Testing of highway engine technology intended to control emissions from highway diesel engines will be conducted generally under the provisions of 40 CFR Part 86 subpart N. The primary emissions measurements will be of NOx, PM, HC, CO, and other FTP required measurements. CO_2 emissions and other measurements described by this protocol are secondary measurements. Each verification test will consist of the same number of tests on the baseline broken-in engine, the de-greened emission control technology, and the aged emission control technology. The number of tests will include a single cold- and hot-start highway transient FTP engine dynamometer test and may include additional hot-start tests in numbers determined using the test design procedure described above. The emissions reductions will be reported as the composite of the cold and mean hot start, as required by the FTP, and as the mean and confidence interval on multiple hot-start tests. The smoke test is not required. The test parameters will be derived from the baseline engine mapping procedure. Emissions reductions will be computed relative to the baseline engine emissions using the same test cycle used during the baseline testing. As required by the FTP, tests that do not meet the FTP QA requirements must be repeated.

The test/QA plan for a specific technology will specify the engines that will be tested and any other aspects of the test that are specific to the technology or the test laboratory.

5.2.3 Highway Test Engines

The emissions characteristics of diesel engines of the same PM certification level are arguably similar because the engine technologies required to achieve those certification levels are likely to be similar. The emissions characteristics are also similar for engine families that have a breadth of technology similar to the tested engine. These similarities may provide an opportunity to group engines and reduce the verification testing burden on applicants. As of the date of this protocol, EPA-OTAQ has proposed allowing the verification result from a single engine test to apply to multiple engines of different manufacturers. This is a decision that has been reserved by EPA-OTAQ, who should be consulted for details regarding the engines required to be tested as part of the verification, the applicability of that verification, and the magnitude of the associated emissions reduction credit under the VRP.

5.2.4 Verification Testing of Nonroad Engines - General

The basic verification test for nonroad engines will consist of the nonroad steady-state mode tests as described in 40 CFR, Part 89, Subpart E, as described further in Section 5.5. The primary emissions measurements will be of NO_x, PM, HC, CO and other FTP required measurements. CO_2 emissions and other measurements described by this protocol are required secondary measurements. Each verification test will consist of one or more full steady-state multimode FTP test(s) on the baseline broken-in engine, the de-greened device, and the aged device. The test condition will be derived from the baseline engine mapping procedure. The test may be conducted over all modes of the Part 89 test or over portions selected by the applicant. The emissions reductions will be reported as the composite mean and confidence interval of the multiple test modes, computed as stated in the FTP.

Composite emissions reductions are computed relative to the composite baseline engine emissions, and will be reported in composite and mode-by-mode to allow flexibility in use of the data for different engine applications.

5.2.5 Nonroad Test Engines

Following an approach similar to that used for the highway engines, the results of verifications conducted on individual nonroad engines may be applicable to broader groups of engines. Technology applicants may select the engines on which to test their technologies. Coordination with EPA-OTAQ is encouraged because this is a decision that has been reserved by EPA-OTAQ, who should be consulted for details regarding the engines required to be tested as part of the verification, the applicability of that verification, and the magnitude of the associated emissions reduction credit under the VRP

5.2.6 De-greening.

For many hardware technologies, a brief period of use (de-greening) is needed to achieve a stable emissions reduction that allows representative testing. For instance, the pressure drop across a continuously regenerating PM filter reaches an equilibrium value. The de-greening time period required varies for different technologies, but is on the order of 25 to 125 hours. In all cases, the technology applicant must propose and justify the extent of the de-greening process in the ETV application. The APCTVC office will review and comment on this proposal, advise regarding the documentation requirements, and will append the de-greening process description to the technology test/QA plan. When complete, the actual process used must be documented. A description of the de-greening process will be included in the verification report.

For purposes of this protocol, de-greening time requirements will be specified by the technology applicant as indicated by either previous testing or the requirements of the data user. To allow flexibility for the applicant, de-greening is not required to be conducted at the test lab. It may be done and documented by the applicant or conducted by the test lab immediately prior to testing. In the latter case, the test lab will ensure that all necessary documentation is provided. Otherwise the applicant must provide the necessary documentation.

De-greening may occur in a laboratory or during in-use field operations on an engine that is equivalent to the proposed ETV test engine, or another engine of the same size which utilizes the same engine technology (and thus falls within the range of the technology's stated applicability.)

5.2.7 Regeneration.

Emissions control devices whose normal operation includes a periodic regeneration will be tested over sufficient test cycles (described below) until a test cycle includes a "regeneration" event. Continuous cleaning PM filters should reach a stable operating range before testing. The verified emissions rate and emissions reduction achieved will be computed as the time-weighted average of the emissions rate and reduction achieved over this complete operating cycle. Technologies that are continuously regenerated in normal operation are not the subject of this paragraph.

5.2.8 Device Scaling.

The performance of most retrofit air pollution control technologies is affected by the relative size of the testing device and the engine. For example, diesel oxidation catalyst (DOC) size -- relative to the engine exhaust rate -- can be expressed by such parameters as reactor space velocity. Active catalyst loading, substrate cell density (cells/unit area) and cell wall thickness can also affect technology performance. If verification results from any single test are to be applied to another engine or another size of the same engine, non-proprietary design information that allows scaling must be available to the APCTVC and the potential technology user (the public) to evaluate proper scaling between engines. Alternatively, an applicant whose technology is being sold in fixed incremental sizes with published ranges of applicability (e.g., model AAA is suitable for 100 to 150 hp engines) will be expected to test on an engine at the most challenging end of the range of applicability. Device scaling and engine selection decisions will be explained and documented in the test/QA plan to the extent possible, and will reported in the verification report. The verification report and statement will report the results and the design guidance required to independently extend application of the technology to other engines in the same engine grouping.

5.2.9 Durability.

The emissions reductions measured for the de-greened air pollution control device will not account for changes in product performance that may occur as the device ages. For participation in the VRP, additional testing of an "aged" control device is required by EPA-OTAQ. This testing is followed by extrapolation of the "initial de-greened" and "aged" verified performance measurement to the end of the warranted life of the control technology using a method determined by EPA-OTAQ and described below as current as of the date of this protocol.

1) Aging entails subjecting the control device to operating conditions that cause normal wear equivalent to at least 25% of the useful life stated in the applicant's ETV application. The technology applicants must conduct the aging process. They have discretion to tailor this process to product requirements. Applicants may age an exhaust catalyst by using it during real-world operation, or through accelerated bench testing. It is expected that vendors will submit identical parts (one in a de-greened state, one aged to at least 25% expected full-life) so that testing with the baseline may occur sequentially. All aging protocols must accompany the ETV application and explain the technical basis for stating the aging protocol results in at least 25% full-life aging. If real-world aging is performed, the application must describe the usage and maintenance history of the aged unit as well as the engine with which it was aged.

2) Emissions testing using the aged device will be part of the ETV verification testing, and will follow the same procedures applied to the de-greened technology. First, baseline emissions testing shall be conducted, followed by testing with the de-greened device, and then finally testing the aged device. An applicant may elect to age a unit to its full useful life prior to testing and request verification on that basis.

3) The full useful-life reduction capabilities will be estimated by EPA-OTAQ following procedures they will provide to applicants.

5.2.10 Standard Diesel Test Fuel.

The standard diesel test fuel for highway engines should meet the EPA specifications outlined in

40 CFR Part 86.1313-98 with the exception of the sulfur content. For nonroad engines the test fuel should be that described in 40 CFR Part 89.330 or another fuel as specified by the control technology applicant. Because the performance and durability of many types of diesel retrofit technology are affected by the sulfur content of the diesel fuel, applicants should specify the maximum sulfur level of the fuel for which their technologies are designed. The sulfur content of the verification test fuel should be no less than 66% of the stated maximum sulfur content. (Because refinery and blending operations are such that very low sulfur content control is difficult, test fuel with a sulfur content of 15 ppm or below is not constrained to the "66% rule". The actual sulfur content of the test fuel batch is to be reported.) Other test fuels should meet the applicable EPA specifications outlined in 40CFR Part 86.1313. Doping of the fuel by the test laboratories s is permissible if necessary to achieve the required fuel sulfur content for either baseline or controlled engine tests. With these strictures, during verifications baseline engines should be fueled with standard fuels that are representative of nominal in-use fuels and controlled engines with low sulfur versions of the standard fuels that are representative of the applicant's recommended or required fuel.

5.2.11 Engine Performance and Power.

Engine performance and power will be measured and reported for both the baseline engine (without the control device installed) and the engine with the control technology. Engine performance measurements will be made with the engine operating at maximum power (rated conditions) and at peak torque as defined in the applicable FTP.

5.2.12 Fuel Consumption.

Fuel consumption will be measured for both the baseline engine (without the control device installed) and the engine with the control device installed to determine the effect of the technology on fuel consumption. The engine fuel consumption measurements will be made at maximum power at rated conditions and at peak torque at intermediate speed. They will be reported as a fractional increase or decrease along with fuel economy and brake specific fuel consumption from testing by the applicable FTP.

5.2.13 Back-pressure.

The back-pressure of a retrofit control technology may affect the performance of an engine, and the ETV verification will measure and report back-pressure with the control device at full-load and rated speed. Back-pressure will be measured and reported for both the baseline engine (without the technology installed) and the engine with the control device installed. The engine backpressure will be set for the verification test as required by the applicable FTP (highway or nonroad).

5.2.14 Control Technology Operating Temperature

Inlet (engine exhaust) and discharge temperatures must be measured for technologies that are either dependent on specific operating temperature ranges or affected by engine or exhaust temperatures.

5.2.15 Other Measurements and Conditions

Verification of technologies that may produce secondary pollutants or have other secondary effects must include measurement of those pollutants in the verification. CO_2 emissions, while not primary, must be measured and estimated using measurement instrumentation and/or from a carbon balance from the fuel usage. Verification must include the appropriate measurements for technologies that require other specific operating conditions or affect emissions over only a limited range of a particular pollutant. For example, because the long-term operation of DOCs and PM filters is affected by the soluble organic fraction (SOF) fraction of the PM, SOF must be measured as part of verification for these and similar technologies. The details of these non-critical measurements and their QA goals will be part of the test/QA plan.

5.3 Verification of Diesel Oxidation Catalysts and PM Filters

5.3.1 Technology Description.

For the purposes of this GVP, diesel oxidation catalysts (DOCs) are defined as devices made up of active catalyst material (often containing precious metal) deposited on a support medium. The engine exhaust passes through the device, where the pollutants catalytically react and more acceptable reaction products are exhausted. PM filters mechanically trap PM emissions and subsequently oxidize them. Filters may also employ a catalyst for gaseous emissions control and to enhance the oxidation of the collected PM.

Physically, DOCs and PM filters have the general appearance of a large muffler, and are placed in the engine exhaust at approximately the same location. They are therefore well-suited to retrofit applications. No external liquid or gaseous reactants are required for them to function.

DOCs have been reported to decrease HC and CO emissions by over 50%. They decrease PM emissions by about 20%. PM filters have been reported to decrease PM and HC emissions by 80% or more, and to decrease CO at about the level achieved by oxidation catalysts. NOx emissions may be decreased slightly by exhaust catalysts.

Operational issues with DOCs and PM Filters are primarily achieving or maintaining adequate temperature within the device to complete the reactions and functioning with an accumulation of catalyst poisons and/or non-combustible lubricant ash residue. Lubricant ash and wear metals can largely be removed by infrequent “blowing” with compressed air. Guidance on technique and frequency of such cleaning should be provided in the verification application.

5.3.2 Test Considerations Specific to DOCs and PM Filters

The general considerations in Section 5.2 apply to DOC and PM filter verification. Verification of DOCs and PM filters requires measurement of the SOF content of the exhaust stream prior to entering the DOC. (The SOF may be measured for PM collected during the baseline engine test.) Both DOC’s and PM filters require measurement of inlet and outlet temperatures.

5.4 Verification of Engine Modifications

5.4.1 Technology Description for Engine Modifications

Engine modifications are defined as any change, integral to an engine (e.g., component modifications or change or engine control system calibration change) that is proposed as an emissions reduction technology. Retrofit engine modifications from independent vendors are expected to be rare because of the need to have the engine manufacturer involved to address warranty concerns on the part of the engine owners.

5.4.2 Test Considerations Specific to Engine Modifications

The general considerations in Section 5.2 apply to engine modification verification. Engine modifications are by their nature specific to the engine being tested, and the use of the engine groupings is not appropriate. Engine modifications whose use is endorsed by engine manufacturers are taken to have no adverse impact on engine durability. Those that are not so endorsed will be evaluated as described in Section 5.2.9. The APCTVC will receive durability data sets from the engine modification applicant. These data will be submitted under contract to an independent engine test laboratory or contractor for evaluation as the initial step in verification. Verification testing will begin only after the contractor issues a report stating that the data shows that engines utilizing the engine modification can be expected to operate satisfactorily for the period between scheduled major engine overhauls. Part of the contractors task will be notification of and solicitation of comments from the engine manufacturer. Any reservations on the part of the engine manufacturer will be noted in the report and, if still in force, on the verification statement.

6.0 REPORTING AND DOCUMENTATION

This section describes the procedures for reporting data in the verification report and the verification statement. The specifics of what data must be included and the format in which the data must be included are addressed in this section (e.g., QA/QC summary forms, raw data collected, photographs / slides / video tapes). The verification test report for each technology will include the verification statement at the front of the report. The verification statement is a short summary of the verification results. An example draft is attached as Appendix A. The verification report (VR), including the verification statement (VS), will be written by the APCTVC based on the test report submitted by the testing organization. The VR and VS will be reviewed by the APCTVC and the technology applicant before being submitted to EPA for review and approval as specified in the ETV QMP.

6.1 Reports

The testing organization will prepare a verification test report that describes and documents the verification testing that was conducted and the results of that testing. The test report includes the following topics:

1) draft VS,
2) introduction,
3) description and identification of product tested,

4) procedures and methods used in testing,
5) statement of operating range over which the test was conducted;
6) summary and discussion of results as required to:
    a) support the VS,
    b) explain and document necessary deviations from test plan, and
    c) discuss QA issues;
7) conclusions and recommendations;
8) references; and
9) appendices
    a) QA/QC activities and results,
    b) raw test data, and
    c) equipment calibration results.

The verification statement will include the following:

10) APCTVC applicant and technology descriptive information,
11) summary of verification test program,
12) results of the verification test,
13) any limitations of the verification results, and
14) brief QA statement.

Review and approval of the draft verification report and statement are as described in Section 3.0. A draft verification statement is attached to this protocol as Appendix A.

6.2 Data Reduction

Data from measurements made as part of the verification test will be reported as emissions rates in g/kWh (g/bhp-hr) and as percentage emission reductions from the baseline engine. The confidence limits will be presented as well as the mean emissions reduction, as discussed in Section 5.1.2. When they would be helpful to the mobile sources community because of established usage, the appropriate English units will be supplied parenthetically.

7.0 DISSEMINATION OF VERIFICATION REPORTS AND STATEMENTS

After a retrofit control technology has been tested and the draft VR and VS received from the testing organization, the APCTVC will send a draft of both to the applicant for review prior to submission to EPA-ORD and release of the approved report to the public. This gives the applicant opportunity to review the results, test methodology, and report terminology while the drafts remain working documents and are not publically accessible. The applicant may submit comments and revisions on the draft statement and report to the APCTVC. The APCTVC will consider these comments and may suggest revisions of its own.

After incorporating appropriate revisions, the draft final VR and VS will be submitted to EPA-ORD for review and approval. Following approval, three copies of the verification report will be provided to the applicant. Distribution of the final verification report, if desired, is at the applicant’s discretion and responsibility. However, approved VSs and VRs will be posted on the

ETV web site for public access without restriction. The VR report appendices will not be posted on the website, but will be publically available from the APCTVC. A signed original VS and VR will be filed and retained by the APCTVC, and signed originals will also be provided to the applicant and to EPA.

8.0 APPLICANT'S OPTIONS IF A TECHNOLOGY PERFORMS BELOW EXPECTATIONS

ETV is not a technology research and development program; technologies submitted for verification are to be commercial-ready and with well-understood performance. Tests that meet the verification data quality requirements are considered valid and suitable for publishing. In the event that a technology fails to meet the applicant's expectations, the applicant may request that a VS not be issued. However, verification reports are always in the public domain. VRs will be written and will be available from EPA-ORD for review by the public regardless of a request not to issue a verification statement, and summaries of the results of verification testing may be published by ETV and/or EPA-OTAQ.

The inclusion of the minimum number of test calculation in this GVP introduces another effect should a technology perform below expectations. As stated above, the technology applicant is required to present an estimate of the emissions reduction to allow the calculation of the number of tests required. This estimate may have been accurate, predicted, or estimated. The test laboratory will compute the emission reduction for the initial test and will recompute the minimum number of tests given the actual emissions reduction. If the measured emissions reduction exceeds the estimate, the verification will proceed to completion.

However, if the measured emissions reduction is less than the applicant's estimate, and the number of tests required to meet the ETV minimum requirements is greater than planned, the test laboratory will contact the applicant as soon as practical regarding the need for additional tests, at the applicant's discretion and expense.

Inability to detect a statistically significant emission reduction (equivalently, failure to have sufficient tests) will prevent completion of the verification, and the results of the verification will be reported publically stating that performance could not be distinguished from 0% reduction. A verification statement will not be issued in these cases.

In either of these cases, the applicant may improve the product and resubmit it under a new model identification for verification testing. VSs for tests of the new product will be issued as they are processed by the APCTVC and EPA-ORD (except that the results for several identical tests performed in rapid succession will all be released at the same time.)

9.0 LIMITATIONS ON TESTING AND REPORTING

To avoid having multiple ETV reports for the same product and to maintain the verification testing as a cooperative effort with applicant , the following restrictions apply to verification testing under this protocol:

1) Applicants may submit only products they manufacture or whose distribution they control. Applicants may not submit for verification testing control devices whose use is not in their control except with the agreement of the manufacturer or vendor.
2) For a given product (e.g., brand and model), APCT policy is that only one ETV verification report and statement will be issued for any single application.
3) Air pollution control technology frequently performs differently in different applications. Applicants may request additional tests of essentially identical technology if it is being applied to pollution sources that are clearly different from those for which verifications have been obtained.

10.0 REQUIREMENTS FOR TEST/QA PLAN

10.1 Quality Management

All testing organizations participating in the Verification of Air Pollution Control Technologies for Highway and Nonroad Use Diesel Engines program must meet the QA/QC requirements defined below and have an adequate quality system to manage the quality of work performed. Documentation and records management must be performed according to the *ETV Quality and Management Plan for the Pilot Period (1995-2000)* (ETV QMP, EPA, 1998a.) Testing organizations must also perform assessments and allow audits by the APCTVC (headed by the APCT QA Officer) and EPA corresponding to those in Section 11.

All testing organizations participating in the Retrofit Air Pollution Control Technologies for Highway and Nonroad Use Diesel Engines Program must have an ISO 9000-accredited (ISO, 1994) or ANSI E4-compliant (ANSI, 1994) quality system and an EPA- or APCTVC-approved QMP.

10.2 Quality Assurance (QA)

All verification testing will be done following an approved test/QA plan that meets *EPA Requirements for Quality Assurance Project Plans* (EPA, 2001a) and Part B, Section 2.2.2 of EPA's ETV QMP (EPA, 1998a). These documents establish the requirements for test/QA plans and the common guidance document, *Guidance for Quality Assurance Project Plans* (EPA, 1998b), provides guidance on how to meet these requirements. The APCT Quality Management Plan (RTI, 1998) implements this guidance for the APCTVC.

Verifications conducted under this generic protocol utilize test procedures described in the FTP (40 CFR Part 86 for highway engines and 40 CFR Part 89 for nonroad engines.) The test/QA plan must describe, in adequate detail, how the FTP test methods are implemented by the testing organization. Replication of the FTP text is neither expected nor desired. The test/QA plan should reference the FTP in detail, by section and subsection, as appropriate for the topic under consideration. Any deviations from the FTP must be identified and explained. Internal standard operating procedures (SOPs) may be referenced provided they are available for audit review. (SOPs need not be incorporated into the test/QA plan except by reference. If considered proprietary to the test organization, they should be clearly marked.) When the FTP offers alternative test procedures or equipment, the test/QA plan must identify the alternative implemented. Similarly, if a range of operating parameters is allowed by the FTP, the specifics of the particular implementation must be provided. For a test organization with multiple test cells, these details may be tabulated and incorporated by attaching the table and identifying the test cell on the test report. Steps the testing organization will take to ensure acceptable data quality in the test results are also identified in the test/QA plan. As above, detailed reference to SOPs, the calibration portions of the FTP, or other available documents is encouraged. Any needed SOPs will be developed in accordance with *Guidance for Preparing Standard Operating Procedures (SOPs)* (EPA, 2001b.)

The testing organization must prepare a test/QA plan and submit it for approval by the APCTVC. The test/QA plan must be approved before the test organization can begin verification testing.

A test/QA plan contains the following elements, the contents of which may be stand alone or include references to the FTP or other widely distributed and publically available source. Legible hand-notated diagrams from the FTP are acceptable. If specific elements are not included, an explanation for not including them must be provided.

1) Title and approval sheet;
2) Table of contents, distribution list;
3) Test description and test objectives;
4) Identification of the critical measurements, data quality objectives (DQOs) and indicators, test schedule, and milestones;
5) Organization of test team and responsibilities of members of that team;
6) Documentation and records;
7) Test design;
8) Sampling procedures;
9) Sample handling and custody;
10) Analytical procedures;
11) Test-specific procedures for assessing data quality indicators;
12) Calibrations and frequency;
13) Data acquisition and data management procedures;
14) Internal systems and performance audits;
15) Corrective action procedures;
16) Assessment reports to EPA;
17) Data reduction, data review, data validation, and data reporting procedures;
18) Reporting of data quality indicators for critical measurements;
19) Limitations of the data; and
20) Any deviations from methods from this generic verification protocol.

The APCTVC will provide a test/QA plan template that illustrates the expectations of the center.

10.3 Additional Requirements To Be Included in the Test/QA Plan

The test/QA plan must include or reference a diagram and description of the extractive gaseous measurement system to be used for the testing and a list of the reference analyzers and measurement ranges to be used for quantifying the concentrations of all gaseous compounds to be measured, including both primary and ancillary pollutants.

The test/QA plan must include or reference a schematic of all sample and test locations, including the inlet and outlet to the technology sampling locations. The location of flow disturbances and the upstream and downstream distances from the sampling ports to those flow disturbances must be noted. The number of traverse points that will be sampled must be provided.

The test/QA plan must include or reference the appropriately detailed descriptions of all measuring devices that will be used during the test.

The test/QA plan must explain or reference the specific techniques to be used for monitoring process conditions appropriately for the source being tested. It must also note the techniques that will be used to estimate any other operational parameters.

The test/QA plan must include and document estimates of historical measurement variability that will be used, as discussed in Section 5.1.1 to compute the number of tests required and provide confidence intervals on single test verifications.

11.0 ASSESSMENT AND RESPONSE

Each independent test laboratory must conduct internal assessments of its quality and technical systems and must allow external assessments of these systems by the APCT Verification Center QA personnel and by EPA QA personnel. After an assessment, the test laboratory will be responsible for developing and implementing corrective actions in response to assessment findings.

As appropriate, the APCTVC and/or EPA will conduct assessments to determine the testing organization's compliance with its test/QA plan. The requirement to conduct assessments is specified in EPA's *Quality and Management Plan for the Pilot Period (1995 - 2000)* (EPA, 1998a), and in RTI's QMP (RTI, 1998.) EPA will assess RTI's compliance with RTI's test/QA plans. RTI will assess the compliance of other organizations with their test/QA plans. The assessments will be conducted according to *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (EPA, 2000) and *Guidance on Assessing Quality Systems* (EPA, 2001.)

11.1 Assessment Types

Quality system assessment - Qualitative assessment of a particular quality system to establish whether the prevailing quality management structure, policies, practices, and procedures meet EPA requirements and are adequate for ensuring that the type and quality of measurements needed are obtained.

Technical systems audit - Qualitative on-site audit of the physical setup of the test. The auditors determine the compliance of testing personnel with the test/QA plan.

Performance evaluation audit - Quantitative audit in which measurement data are independently obtained and compared with routinely obtained data to evaluate the accuracy (bias and precision) of a measurement system.

Audit of data quality - Qualitative and quantitative audit in which data and data handling are reviewed and data quality and data usability are assessed.

Surveillance audit- Observation of ongoing work to document conformance with specified requirements and/or procedures, such as those given in a test/QA plan or SOP.

11.2 Assessment Frequency

Activities performed during technology verification performance operations that affect the quality of the data shall be assessed regularly, and the findings reported to management to ensure that the requirements stated in the generic verification protocols and the test/QA plans are being implemented as prescribed.

The types and minimum frequency of assessments for the ETV Program are listed in Part A Section 9.0 of EPA's *Quality and Management Plan for the Pilot Period (1995 - 2000).* Tests conducted during the APCTVC will have at a minimum the following types and numbers of assessments:

1) <u>Technical systems audits and surveillance audits</u>: Self-assessments by test laboratory as provided for in the test/QA plan and at least one independent assessment of the test laboratory.
2) <u>Performance evaluation audits</u>: Self-assessments by test laboratory as provided for in the test/QA plan and at least one independent assessment of the test laboratory.
3) <u>Audits of data quality</u>: Self-assessments by the test laboratory of at least 10% of all the verification data with detailed report of the audit results to be included in the data package sent to the APCTVC for review.
4) Assessements of quality systems: Self-assessments by the test laboratory as provided for in the test/QA plan and at least one independent assessment of the test laboratory.

The independent assessments of tests conducted by RTI will be performed by EPA. The independent assessments of other organizations will be by RTI.

11.3 Response to Assessment

When needed, appropriate corrective actions shall be taken and their adequacy verified and documented in response to the findings of the assessments. Data found to have been taken from non-conforming technology shall be evaluated to determine its impact on the quality of the required data. The impact and the action taken shall be documented. Assessments are conducted according to procedures contained in the APCT QMP. Findings are provided in audit reports. Responses by the testing company to adverse findings are required within 10 working days of receiving the audit report. Follow up by the auditors and documentation of responses are required.

12.0 SAFETY MEASURES

12.1 Safety Responsibilities

The test organization's project leader is responsible for ensuring compliance with all applicable occupational health and safety requirements. Each individual staff member is expected to follow the requirements and identify personnel who deviate from them and report such action to their supervisor.

12.2 Safety Program

The test company must maintain a comprehensive safety program and ensure that all test personnel are familiar with and follow it.

13.0 REFERENCES

ASQC. *AMERICAN NATIONAL STANDARD Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs*. ANSI/ASQC E4-1994. Milwaukee, WI. American Society for Quality Control, 1994.

ASTM. *Standard Test Method for Cetane Number of Diesel Fuel Oil.* ASTM D613-95. American Society for Testing and Materials, West Conshohocken, PA, 1995.

ASTM. *Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry*. ASTM D2622-98. American Society for Testing and Materials, West Conshohocken, PA, 1998

ASTM. *Standard Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water*. ASTM D665-99. American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Determination of Aromatic Content and Polynuclear* ASTM. *Standard Test Method for Hydrocarbon Types in Middle Distillates by Mass Spectrometry*. ASTM D2425-99. American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Cloud Point of Petroleum Products*. ASTM D2500-99 American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Filterability of Diesel Fuels by Low-Temperature Flow Test (LTFT)*. ASTM D4539-98. American Society for Testing and Materials, West Conshohocken, PA, 1998.

Aromatic Content of Diesel Fuels and Aviation Turbine Fuels by Supercritical Fluid Chromatography. ASTM D5186-99. American Society for Testing and Materials, West

Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE).* ASTM D6078-99. American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR).* ASTM D6079-99. American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels*. ASTM D6371-99. American Society for Testing and Materials, West Conshohocken, PA, 1999.

ASTM. *Standard Test Method for High Temperature Stability of Distillate Fuels*. ASTM D6468-99. American Society for Testing and Materials, West Conshohocken, PA, 1999

ASTM. *Standard Test Methods for Flash-Point by Pensky-Martens Closed Cup Tester*. ASTM D93-00. American Society for Testing and Materials, West Conshohocken, PA, 2000.

ASTM. *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter*. ASTM D240-00. American Society for Testing and Materials, West Conshohocken, PA, 2000.

EPA. *Environmental Technology Verification Program, Quality and Management Plan for the Pilot Period (1995-2000).* EPA 600/R-98/064. http://www.epa.gov/etv/qmp.htm, Cincinnati, OH. National Risk Management Research Laboratory - National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. May 1998a.

EPA. *EPA Guidance for Quality Assurance Project Plans. EPA QA/G-5*, EPA/600/R-98/018, http://es.epa.gov/quality/qs-docs/g5-final.pdf, Washington, DC. Office of Research and Development, U. S. Environmental Protection Agency, February1998b.

EPA. *EPA Requirements for Quality Assurance Project Plans. EPA QA/R-5*, EPA/240/B-01/003, http://www.epa.gov/quality/qs-docs/r5-final.pdf, Washington, DC. Office of Environmental Information, U. S. Environmental Protection Agency, March 2001.

EPA. *Guidance on Technical Audits and Related Assessments for Environmental Data Operations*, *EPA QA/G-7*, EPA/600/R-99/080, http://www.epa.gov/quality/qs-docs/g7-final.pdf, Washington, DC. Office of Environmental Information, U.S. Environmental Protection Agency. January 2000.

EPA. *Guidance for the Preparing Standard Operating Procedures (SOPs). EPA QA/G-6*. EPA 240/B-01/004. http://www.epa.gov/quality/qs-docs/g6-final.pdf, Washington DC. Office of Environmental Information, U.S. Environmental Protection Agency. March, 2001.

EPA. Guidance on Assessing Quality Systems (Quality Staff Draft). EPA QA/G-3.

Washington, DC. Office of Environmental Information, U. S. Environmental Protection Agency. August, 2001.

ISO. *ISO 9001-1994, Quality Systems Model for Quality Assurance in Design, Development, Production, Installation, and Servicing*. International Organization for Standardization. Geneva, Switzerland. In USA, American National Standards Institute, New York, NY. 1994.

RTI. *Verification Testing of Air Pollution Control Technology - Quality Management Plan*. Air Pollution Control Technology Program. J. R. Farmer, Program Director, Research Triangle Institute, Research Triangle Park, NC. 1998.

Ullman, Terry. 2001. Private communication to D. W. VanOsdell.

U.S. Government. 1999. Protection of Environment. Title 40, Part 86, Code of Federal Regulations, as of July 1, 1999. Washington, DC. Office of the Federal Register.

U.S. Government. 1999. Protection of Environment. Title 40, Part 89, Code of Federal Regulations, as of July 1, 1999. Washington, DC. Office of the Federal Register.

APPENDIX A: EXAMPLE VERIFICATION STATEMENT

Appendix A is an example verification statement written for a generic PM filter control technology. The technology is assumed to be directed at a highway use engine. It is assumed to be an efficient control device, requiring only a single test by the minimum-number-of-test calculation. The PM values in Table A-2 are taken from the 85% reduction column of Table 3, while the other values are completely hypothetical.

This generic verification statement is intended only to show the form of a verification statement. It will require modification for each technology verified, depending on the details of that technology's design, construction, and operation. The test/QA plan written for each test will include a draft verification statement customized for the technology actually being tested. The text of that specific verification statement will address the significant parameters that apply to the technology tested.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

EPA
U.S. Environmental Protection Agency

RTI
Research Triangle Institute

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MOBILE DIESEL ENGINE AIR POLLUTION CONTROL TECHNOLOGY**		
APPLICATION:	**CONTROL OF EMISSIONS FROM MOBILE DIESEL ENGINES IN (*HIGHWAY*) (*NONROAD*) USE BY (*TECHNOLOGY TYPE*)**		
TECHNOLOGY NAME:	**TECHNOLOGY NAME**		
COMPANY:	**COMPANY NAME**		
ADDRESS:	**ADDRESS** **CITY, STATE ZIP**	**PHONE:** **FAX:**	**(000) 000-0000** **(000) 000-0000**

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups which consist of buyers, vendor organizations, permitters, and other interested parties; with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology Verification Center (APCTVC), one of six centers under ETV Program , is operated by the Research Triangle Institute (RTI), in cooperation with EPA’s National Risk Management Research Laboratory. The APCTVC has evaluated the performance of a ________ *TYPE* ______ emission control technology for mobile diesel engines, the *TECHNOLOGY NAME* by *COMPANY NAME*.

VERIFICATION TEST DESCRIPTION

All tests were performed in accordance with the APCTVC *Generic Verification Protocol for Diesel Oxidation Catalysts, PM Filters, and Engine Modification Technologies for Highway and Nonroad Use Diesel Engines* and the specific technology test plan "Verification Test/QA Plan for TECHNOLOGY NAME" These documents include requirements for quality management, quality assurance, procedures for product selection, auditing of the test laboratories, and test reporting format.

The mobile diesel engine air pollution control technology was tested at *TEST LABORATORY*. The performance verified was the percentage emission reduction achieved by the technology for PM, NO_x, HC, and CO relative to the performance of the same baseline engine without the technology in place. Operating conditions were documented and ancillary performance measurements also made. The basic modules of the test procedure are found in the federal test procedures (FTPs) for highway engines (40CFR, Part 86, Subpart N) and nonroad engines (40CFR, Part 89, Subpart E). For highway use, a single full FTP test was conducted, followed additional hot start transient tests as needed to meet the requirements of the GVP. For nonroad use, one or more multimode test were conducted as described in the GVP. A summary description of the verification test is provided in Table A-1.

Table A-1. Summary of the conditions for verification test of *TECHNOLOGY NAME* on ENGINE DESCRIPTION.

FTP Test Conducted	Highway Transient FTP
Engine Family ID	*ENGINE MFGR NAME* Series *XXXYYY*, ??? operating hours prior to test
Engine Size, hp	XXX hp
Technology ID	ACME Mark II PM Trap, Model AAA1 for diesel engines up to 150hp on standard fuel
Technology description	Honeycomb PM filter packaged in an muffler-sized can for retrofit installation by retail level mechanic. No engine modifications required.
Test cycle or mode description	1 full FTP test (1 cold start and 1 hot start)
Test fuel description	EPA standard diesel per 40 CFR Part 86.1313-98
Critical measurements	PM, NOx, HC, and CO per the FTP
Ancillary measurements	CO2, backpressure at engine exhaust port, exhaust temperature, fuel consumption, regeneration requirements

VERIFIED TECHNOLOGY DESCRIPTION

This verification statement is applicable to the *TECHNOLOGY NAME* (to include model number and other identifying information as needed), which is an cordierite-based PM filter manufactured by *MANUFACTURER NAME*. *TECHNOLOGY NAME* is packaged and marketed for particular engine families (for example, Model X???? is properly sized for the YYYYY engine) or as a unit suitable for use on engines below a particular diesel hp rating. The unit whose performance was verified was the Model XXX1, which is rated for engines up to 150 hp, fuelled by standard diesel fuel.

This verification statement describes the performance of *TECHNOLOGY NAME* on the diesel engine identified in Table A-1. A retrofit device, *TECHNOLOGY NAME* is expected to provide similar emissions control performance on other engines having similar exhaust stream characteristics (similar fuel and engine technology) when properly sized for the application.

VERIFICATION OF PERFORMANCE

TECHNOLOGY NAME achieved the emissions reduction stated in Table A-2 at the stated conditions. The number of required ETV verification tests was estimated to be one complete FTP test, and this estimate was confirmed by the verification test results. Table A-2 may include both verification results for both the initial operation (degreened) and for the technology following the stated period of aging.

Table A-2. Verified emissions reductions for hypothetical *TECHNOLOGY NAME*

	Degreened (XXX hours) Technology Test			**Aged (XXX hours) Technology Test**		
	Baseline Engine	Controlled Engine	Emissions Reduction %	Baseline Engine	Controlled Engine	Emissions Reduction %
Critical Measurements						
PM Emissions for hot-start	0.8 g/kWh (0.6 g/bhp-h)	0.012 g/kWh (0.09 g/bhp-h)	85%±3%	0.79 g/kWh (0.59 g/bhp-h)	0.012 g/kWh (0.091 g/bhp-h)	84.6%±3%
PM Emission composited						
NO_x Emission for hot-start						
NO_x Emission composited						
HC Emissions						
CO Emissions						
Ancillary Measurements						
Engine Power						
Peak Torque						
CO_2 Emissions						
PM SOF						
Exhaust Flow						
Exhaust Temp.						
Backpressure						
Fuel Useage						
In/Out Temp.						
Regeneration						

Maintenance Schedule for TECHNOLOGY	
Comments	

For the purposes of determining the status of the technology in regard to EPA's voluntary retrofit program, the prospective user is encouraged to contact EPA-Office of Transportation and Air Quality (OTAQ) or visit the retrofit program web site at http://www.epa.gov/otaq/retrofit/.

The APCT QA Officer has reviewed the test results and quality control data and has concluded that data quality objectives given in the generic verification protocol and test/QA have been attained.

During the verification tests, EPA and/or APCTVC quality assurance staff conducted technical assessments at the test laboratory, these confirm that the verification test was conducted in accordance with the test laboratory's EPA-approved test/QA plan.

This verification statement verifies the emissions characteristics of *TECHNOLOGY NAME* within the stated range of application. Extrapolation outside that range should be done with caution and an understanding of the scientific principles that control the performance of *TECHNOLOGY NAME*.

In accordance with the generic verification protocol, this verification report is valid commencing on *DATE* indefinitely for application of *TECHNOLOGY NAME* within the range of applicability of the statement.

__________________________	__________________________
E. Timothy Oppelt Date	Jack R. Farmer Date
Director	Program Director
National Risk Management Research Laboratory	Air Pollution Control Technology Verification Center
Office of Research and Development	Research Triangle Institute
United States Environmental Protection Agency	

NOTICE: ETV verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and RTI make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of commercial product names does not imply endorsement.

Appendix B: Example Calculation of Minimum Number of Tests

The calculation of the minimum number of tests required for verification is explained and the basic equation presented in Section 5.1.1. This appendix presents example calculations to illustrate the procedure.

As explained in Section 5.1.1, the calculation is based on:

1) PM and NO_x hot-start FTP emissions measurement variability experience for the Southwest Research Institute (SwRI) diesel emissions laboratory, which is a function of both the measurement and the emissions level;
2) a baseline mean emission (assumed to be the cert value); and
3) a mean controlled emission (the product of the baseline emission and the expected emissions reduction.

The criteria being used is that the minimum number of hot-start FTP tests required for verification is the number of tests required to have a 90% probability of detecting the specified emission reduction at the 95% confidence level. The basic equation being used for the calculation is:

$$n \approx (z_\alpha + z_\beta)^2 \, (\sigma^2_1 + (1 - \delta/100)^2 \cdot \sigma^2_2) \, / \, \delta^2$$

where:

n	=	sample size in each group, rounded up to the next integer;
δ	=	difference between baseline and controlled engine emissions mean, expressed as a percent of the baseline emission value;
σ^2_1	=	squared standard deviation of baseline-engine emission data, expressed as a percent of the baseline emission certification value;
σ^2_2	=	squared standard deviation of controlled-engine emission data, expressed as a percent of the baseline emission certification value;
$1 - \alpha$	=	confidence coefficient on comparison of means (0.95 minimum for ETV);
$1 - \beta$	=	probability of detection of reduction (0.90 minimum for ETV);
z_α	=	normal distribution value corresponding to upper-tail probability of α; and
z_β	=	normal distribution value corresponding to upper-tail probability of β.

Note that σ_1, σ_2, and δ, are expressed as percentages of the baseline emission certification value. This transformation was required to simplify the equation and allow it to be presented in the form shown in Tables 1 and 2. The parameter 'z' is tabulated under different names in statistics reference texts. It is the 'z' value corresponding to 'the tail area of the unit normal distribution' in Box, Hunter, and Hunter (1978). In the Standard Mathematical Tables (CRC, 1968), 'z' is known as 'x', and the tail area is labeled '1 - F(x)', where F(x) is the cumulative distribution function of a standardized normal random variable. To obtain the value of 'z' from the statistical tables, α (or β) is the probability (ranging from 0.5000 to 0.0000) in the body of the table, and 'z' is read (or interpolated) from the appropriate column and/or row, ranging from 0.00 to 4.00 over the same range.

The value 'z' can be calculated within an EXCEL® or QUATTRO PRO® spreadsheet as the absolute value of the function returning the inverse of the standard normal cumulative distribution, NORMSINV(probability), by setting probability equal to α or β, as appropriate.

Table B-1 gives a step-by-step calculation example drawn from Table 1 for a 90% probability (β = 0.10) of detecting a 5% emission reduction at the 95% confidence level (α = 0.05) and from Table 2 for an 80% probability (β = 0.20) of detecting a 50% emission reduction at the 95% confidence level.

Table B-1. Example calculation of minimum number of verification tests.

	Table 1, Col.1	Table 2, Col. 3
Emission reduction relative to baseline (certification) emission, δ	5%	50%
Measurement variability at specified emission reduction, σ_2	2%	7%
Measurement variability for baseline engine, σ_1	2%	2%
α	0.05	0.05
z_α	1.645	1.645
β	0.10	0.20
z_β	1.282	0.842
$(\sigma^2{}_1 + (1 - \delta/100)^2 \cdot \sigma^2{}_2) / \delta^2$	0.304	0.007
$(z_\alpha + z_\beta)^2 (\sigma^2{}_1 + (1 - \delta/100)^2 \cdot \sigma^2{}_2) / \delta^2$	2.61	0.040
minimum number of tests, n	3	1

Appendix C: Sensitivity of Test Number Calculation to Test Variability

Table C-1 presents the results of a sensitivity analysis of the calculation of the required number of tests in the particular cases of high (85%) and low (10% and 5%) reductions in emissions. The number of tests reported in the final column is the number required to have a 90% probability of detecting the emissions reduction with 95% confidence. The equation in Section 5.1.1 was used to compute the required number of tests.

Within Table C-1, the variability of the baseline engine measurement ranges from 2% to 30%, and the controlled engine measurement variability from 10% to 30%. All of the percentage numbers in the table are referenced to a baseline engine emission. To convert the percentages to an absolute emission rate, they must be multiplied by a baseline engine emission rate, and at 30% variability the standard deviations are twice the emission rate in g/bhp-hr. The emissions and standard deviations in Table C-1 have all been calculated for a baseline engine emitting PM at the 1990 certification level of 0.6 g/bhp-hr. For example, from the first row, an 85% reduction means an absolute PM emission of 0.09 g/bhp-hr. A 10% controlled engine measurement variability means the standard deviation for that measurement is 0.06 g/bhp-hr. For the baseline engine, the variability is 2%, so the baseline engine standard deviation is 0.012 g/bhp-hr. The same approach can be used to make a similar table for any other emission rate by multiplying the percentages by the desired baseline emission rate.

While the number of required tests increases as the test variability increases, Table C-1 shows that the increase is modest at high emissions reduction levels. While higher variability is expected at higher levels of control because the absolute emissions concentrations are low, the large reduction in emissions is easily detected.

On the other hand, lower variability is expected for low emissions reductions, but the smaller changes are harder to detect and more tests are required. Therefore even modest variability levels (relative to those in the top block of Table C-1) lead to very large numbers of tests.

Table C-1. Sensitivity of number of tests to measurement variability

Expected emissions reduction, %	Controlled engine emissions, g/bhp-hr, relative to a baseline engine at the 1990 PM certification emission limit	Controlled engine variability, % of baseline engine	Controlled engine standard deviation, g/bhp-hr for baseline emission of 0.6 g/bhp-hr	Baseline engine variability, %, with the 1990 certification limit as baseline	Baseline engine standard deviation, g/bhp-hr, for1990 emission limit baseline emission of 0.6 g/bhp-hr	Number of tests to achieve 90% probability of detecting reduction with 95% confidence
85	0.09	10	0.06	2	0.012	1
85	0.09	15	0.09	2	0.012	1
85	0.09	20	0.12	2	0.012	1
85	0.09	30	0.18	2	0.012	1
85	0.09	10	0.06	10	0.060	1
85	0.09	15	0.09	10	0.060	1
85	0.09	20	0.12	10	0.060	1
85	0.09	30	0.18	10	0.060	1
85	0.09	10	0.06	30	0.150	2
85	0.09	15	0.09	30	0.150	2
85	0.09	20	0.12	30	0.150	2
85	0.09	30	0.18	30	0.150	2
10	0.54	2	0.012	2	0.012	1
10	0.54	4	0.024	4	0.024	3
10	0.54	6	0.036	6	0.036	6
10	0.54	8	0.048	8	0.480	10
10	0.54	10	0.06	10	0.060	16
5	0.57	2	0.012	2	0.012	3
5	0.57	4	0.024	4	0.024	11
5	0.57	6	0.036	6	0.036	24
5	0.57	8	0.048	8	0.480	42
5	0.57	10	0.06	10	0.060	66